Do metacognitive elements facilitate the training of executive functions? A pilot study

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Abstract

The aim of the current study was to develop and pilot a new executive function (EF) training paradigm designed to maximize transfer to untrained EF tasks by targeting metacognitive coordination of EF processes. Participants were 198 children who were tested individually in a single session, 100 aged 4-5 years and 98 aged 8-9 years. All participants carried out a working memory (WM) training task, the type of which depended on their allocated condition; verbal WM + metacognition, visuospatial WM + metacognition, verbal WM-only or visuospatial WM-only. The WM + metacognition training tasks included metacognitive elements, short activities encouraging children to reflect on task demands and potential strategies. The WM-only training tasks did not include these metacognitive elements. All participants completed the same verbal and visuospatial WM pre- and post-tests, before and after training. Results showed that the WM + metacognition groups did not gain more from training than the WM-only groups. As all data were collected in a single session, there might not have been enough opportunity for the metacognitive elements to come into effect. Future steps involve delivering the intervention in primary schools, with multiple sessions per participant, targeting children from low socioeconomic backgrounds.

Keywords: Working memory, cognitive training, metacognitive control.

Acknowledgements

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Contents

Introduction

In order to carry out daily activities, we need to control our thoughts and actions. No matter the task at hand, we need this control to focus on the demands of the task. This form of control can be especially difficult for young children, one reason being that their executive functions, which are required for regulating and controlling one's thoughts and actions, are not fully developed.

Executive functions are higher-order cognitive processes linked to activity in the prefrontal cortex (Cuevas et al., 2014). Most researchers have adopted a tripartite definition of executive functions, introduced by Miyake et al. (2000), which consists of cognitive flexibility, inhibitory control, and working memory. Cognitive flexibility enables one to switch between different tasks, such as shifting gears and looking in the rear-view mirror while driving a car. Inhibitory control involves holding back on actions that are inappropriate in a given situation, such as hitting the accelerator when a red light is approaching. Working memory allows one to retrieve and use important information, such as following road signs correctly.

Indicators of executive control are detectable between the age of 8 and 12 months (Diamond, 2006), but the three-part structure of executive functions, mentioned above, seems not to emerge until around the age of 15 (Lee, Bull, & Ho, 2013). Executive functions develop and improve with age, which comes hand in hand with changes in thickness of the prefrontal cortex (Huizinga, Dolan, & van der Molen, 2006; Tamnes et al., 2010), the area of the brain that is the last to attain peak thickness (Shaw et al., 2008). Though many studies have demonstrated the links between executive functions and the prefrontal cortex, several other parts of the brain seem to come into play as well (Karbach & Unger, 2014). Executive functions, as well as the prefrontal cortex, continue developing until adulthood (Tamnes et al., 2010).

Executive functions are linked to many important life outcomes such as school readiness (Blair & Peters, 2010), academic achievement (Borella, Carretti, & Pelegrina, 2010; Bull & Scerif, 2010), social understanding, and interpersonal relationships (Hughes, 2011; Rotenberg, Michalik, Eisenberg, & Betts, 2008). Furthermore, poor childhood self-control, where executive functions play a large role, has been shown to predict adverse outcomes relating to physical health, substance dependence, financial situation and criminal offending later in life (Moffitt et al., 2011).

With the aim of preventing risk for adverse outcomes later in life, efforts have been made to train executive functions in children and adolescents. These efforts have been met with somewhat mixed success (Diamond, 2012; Diamond & Ling, 2016; Karbach & Unger, 2014). In a recent review, Diamond and Ling (2016) go over the existing literature on effective interventions aimed towards improving executive functions. They present a pattern of conclusions throughout the studies included in the review. First, where transfer was observed, the transfer effects to untrained tasks appeared to be limited. For example, working memory training might have resulted in improved working memory, but no changes in attention or self-control, which evidently would have been the aim. Second, training gains depended on the quantity of the training; more training sessions resulted in more training gains. Third, outside factors relating to the way an intervention is presented may have influenced the effectiveness of the intervention. For example, if the person carrying out an intervention programme was motivated and strongly believed in the effectiveness of the paradigm, or if the local community supported it, the likelihood of the intervention being successful may have been higher than if these characteristics would not have been present. Fourth, to be effective, training programmes had to constantly challenge the executive functioning abilities of the participants. Furthermore, for many of the studies, differences between training groups and control groups only appeared when the executive function skills of the participants were pushed near their limits. Fifth, those with the lowest executive function abilities gained the most from training. For example, a study by Blair and Raver (2014), included in the review of Diamond and Ling (2016), demonstrated that children from low socioeconomic backgrounds showed poorer executive function performance than children from high socioeconomic backgrounds, and furthermore, that they improved more from an executive function intervention.

The review of Karbach and Unger (2014) echoes the limitations Diamond and Ling (2016) mention regarding training programmes resulting in limited transfer to untrained tasks. They argue that transfer effects are most likely to appear if the transfer tasks target similar processes or brain areas to the training tasks, and/or when the training paradigms target procedural techniques rather than strategies for specific tasks.

Now the question arises, what sort of procedural techniques should the training paradigms be targeting? Zelazo (2004) argues that developmental changes in executive functions are related to differences in consciousness and how much children are able to reflect on their own cognitive abilities when faced with a task. Chevalier and Blaye (2016) support this view and link it to the qualitative shift from reactive to proactive cognitive control in middle childhood. They argue that the development of executive control is, in part, driven by increased monitoring of control engagement, which improves with age (Chevalier, 2015; Chevalier & Blaye, 2016). Proactive control involves planning how to deal with the demands of a certain task, before it occurs. This requires monitoring of one's own previous performance and cognitive control on a similar task. Young children have a bias towards reactive control, that is, to respond to the demands of a task when the task itself has already been presented. As children grow older, however, they more flexibly engage control either reactively or proactively, by matching potential strategies with the demands of the task at hand (Chatham, Frank, & Munakata, 2009; Chevalier, James, Wiebe, Nelson, & Espy, 2014; Braver, 2012). Chevalier, Martis, Curran, and Munakata (2015) showed that even though young children have a tendency to engage in reactive control, they have the ability to, and do engage in proactive control when the use of reactive control is made difficult. This suggests that rigid engagement of reactive control at that age may stem from poor metacognitive coordination of cognitive control rather than fundamental cognitive limitations (e.g. poor working memory). Chevalier and Blaye (2016) argue that interventions aimed to improve executive functions should target these metacognitive processes; how children adjust their cognitive control based on information gathered by reflecting on their performance on a task.

The aims of the current study are to develop and pilot a novel working memory (WM) intervention for children in two age groups; 4 and 5-year olds and 8 and 9-year olds. The intervention will address the above-mentioned limitations of existing executive function training paradigms by incorporating metacognitive elements in the training procedure. These metacognitive elements are designed to get participants to reflect on their own performance and beneficial strategies relating to the task at hand. Four training conditions will be tested; (i) verbal WM training with metacognitive elements, (ii) visuospatial WM training with metacognitive elements, (iii) verbal WM training without metacognitive elements, and (iv) visuospatial WM training without metacognitive elements. Verbal WM and visuospatial WM will also be tested before and after training. Furthermore, family socioeconomic status (SES) will be measured. Participants will be tested individually in a single session. Due to time constraints, only the WM aspect of executive functions will be targeted at this stage.

Three hypotheses are put forth. First, it is hypothesised that the verbal and visuospatial WM training paradigms that include metacognitive elements will result in more improvements than the WM-only paradigms. Second, it is hypothesised that the effects of training will differ by age, with the younger groups benefitting more from the training than the older groups. Third, it is hypothesised that the effects of training will differ by family SES, with those from lower SES families benefitting more from the training than those from higher SES families.

Methods

Participants

Participants were 198 children in two age groups; 100 aged 4-5 years (*M* = 61 months, *SD* = 7 months, range = 48-72 months), and 98 aged 8-9 years (*M* = 106 months, *SD* = 7 months, range = 96-119 months). The younger group consisted of 43 girls and 57 boys, and the older group consisted of 42 girls and 56 boys. Around half of the sample was recruited and tested in Edinburgh, Scotland and the other half in Erfurt and Frankfurt, Germany. Information about parents' education is provided in Table 1 below.

Table 1

Highest academic qualification completed by the accompanying parent and their partner.

	Scottish sample		German sample	
	Parent	Partner	Parent	Partner
GCSE (or equivalent)	3.9%	4.1%	9.5%	4.9%
A-Levels (or equivalent) or Vocational Training	6.8%	11.3%	39.3%	50.6%
Bachelor's Degree	38.2%	30.0%	4.8%	6.2%
Master's Degree	26.5%	30.1%	40.5%	29.6%
Doctorate	22.5%	19.6%	4.8%	8.6%
None of the above	2.0%	4.1%	1.2%	0.0%

Exclusion criteria. In total, 238 participants took part in the study. In the Scottish sample, 13 participants, of which 12 were in the younger group, did not finish the tasks and were thus excluded from the sample. Likewise, two participants, both in the older group, were excluded from the sample and replaced as they had psychiatric diagnoses. In the German sample, 21 participants, of which 19 were in the younger group, did not finish the tasks and were excluded. In addition, four participants, all in the older group, were excluded because of psychiatric diagnoses. Data from excluded participants were not used for any analyses.

Sampling procedures

Participants for the Scottish sample were recruited through a participant database at the University of Edinburgh (54%) and through advertisement on social media and establishments providing services for children (46%). Response rate from the University of Edinburgh participant database was around 30%. Participants in the older group of the German sample were recruited through schools (50%), a participant database and advertisements in local afternoon programmes (50%). The majority (95%) of the participants in the younger group were recruited from kindergarten. Accompanying parents were compensated £10 (Scottish sample) or €10 (German sample) and the children received a small, age appropriate gift. Kindergartens, where data collection took place, were compensated around €3.33 per participant. Participants' parents provided written informed consent. All study procedures were approved by the Psychology Research Ethics Committee at the University of Edinburgh and the equivalent in Germany.

Procedure and design

All participants were tested individually in laboratories in Edinburgh and Frankfurt, or in kindergartens and schools in Erfurt. Participants were tested in a single session, lasting from 50 to 90 minutes. All participants completed the same tasks measuring language proficiency (PPVT) and verbal speed (Colour-naming task). They then completed three phases of WM tasks: pre-test, training and post-test. The pre-test and post-test phases consisted of the same verbal WM task and a visuospatial WM task. There were four training conditions; verbal WM + metacognition, visuospatial WM + metacognition, verbal WM-only and visuospatial WM-only. The WM + metacognition and WM-only conditions were exactly the same, except the former included metacognitive elements, short activities encouraging children to reflect on task demands and potential strategies, and the latter contained neutral control elements. Participants were divided equally into the four conditions. A visual representation of task order is provided in Figure 1.

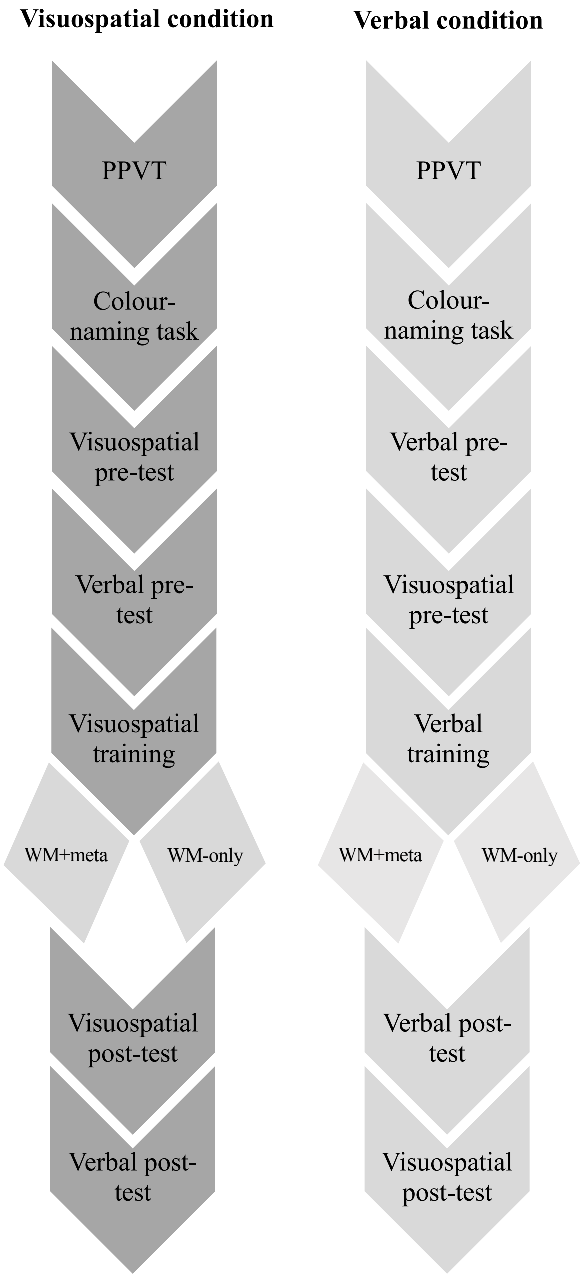

Figure 1. Order of tasks for each training condition.

Materials

Vocabulary and verbal speed. At the start of each session, participants completed a task of language proficiency; an adapted version of the Peabody Picture Vocabulary Test (PPVT-4) (Dunn & Dunn, 2007), and a colour-naming task; a measure of verbal speed (Karbach, Kray, & Hommel, 2011). These two measures served the purpose of baseline matching variables. The PPVT-4 consisted of 22 pages, each containing four pictures. The experimenter said a word that matched one of the four pictures and the participants were asked to point to the matching picture. Responses were scored as correct = 1 and incorrect = 0 and a total score reflecting the sum of correct responses was computed.

In the colour-naming task, participants saw a sheet of paper with four different shapes, in four different colours, at the top; a yellow circle, blue cross, red triangle, and green square. Below were 48 more shapes of the same kind; circles, crosses, triangles and squares, in a random order, but all had a white fill and black outline. Participants were asked to name the colour that matched each shape and complete as many shapes as they could, as quickly and accurately as possible, in 45 seconds. The first five shapes were practice and not included in the 45 second test phase. Responses for each item were scored correct = 1 and incorrect = 0, and a total score reflecting the sum of correct items was computed. The task sheet is presented in Appendix A.

Working memory pre- and post-tests. In the verbal WM pre- and post-tests, participants saw a picture of a food item appear on a screen in front of them and heard the corresponding food name. The first step was a processing task; participants were asked to indicate whether the picture was big or small by clicking on corresponding items in the lower corners of the screen with a computer mouse. After that, there was a recall phase; a selection of 8 food pictures appeared on the screen and participants were asked to click on the food item they had just seen/heard (Figure 2a). The number of food items presented depended on participants' performance; if participants correctly indicated the size of the food item and selected the correct item in the first trial, the next trial would contain two food items and then three items if responses were correct in that trial as well and so on and so forth. If a participant responded incorrectly in trials containing two or more items, the next trial would contain one less item. Each verbal WM pre- and post-test contained 12 trials.

The visuospatial WM pre- and post-tests were adapted versions of the Corsi Block-Tapping Task (Berch, Krikorian, & Huha, 1998; Pagulayan, Busch, Medina, Bartok, & Krikorian, 2006). Participants saw a 3x3 grid on a computer screen in front of them. In one of the squares on the grid, there was a picture of an apple, either whole or partly eaten. In the processing task, participants were asked to indicate whether the apple was whole or eaten by clicking on corresponding pictures in the lower corners of the screen. After that, there was a recall phase; an empty 3x3 grid appeared and participants were asked to click on the square where they had seen the apple (Figure 2b). As in the verbal WM pre- and post-tests, the number of apples presented depended on participants' performance. If participants correctly indicated if the apple was whole or eaten and clicked on the correct square on the grid in the first trial, they would see two apples in the next trial and so on. Equally, if participants responded incorrectly in trials containing two or more apples, the next trial would contain one less item. Each visuospatial WM pre- and post-test contained 12 trials.

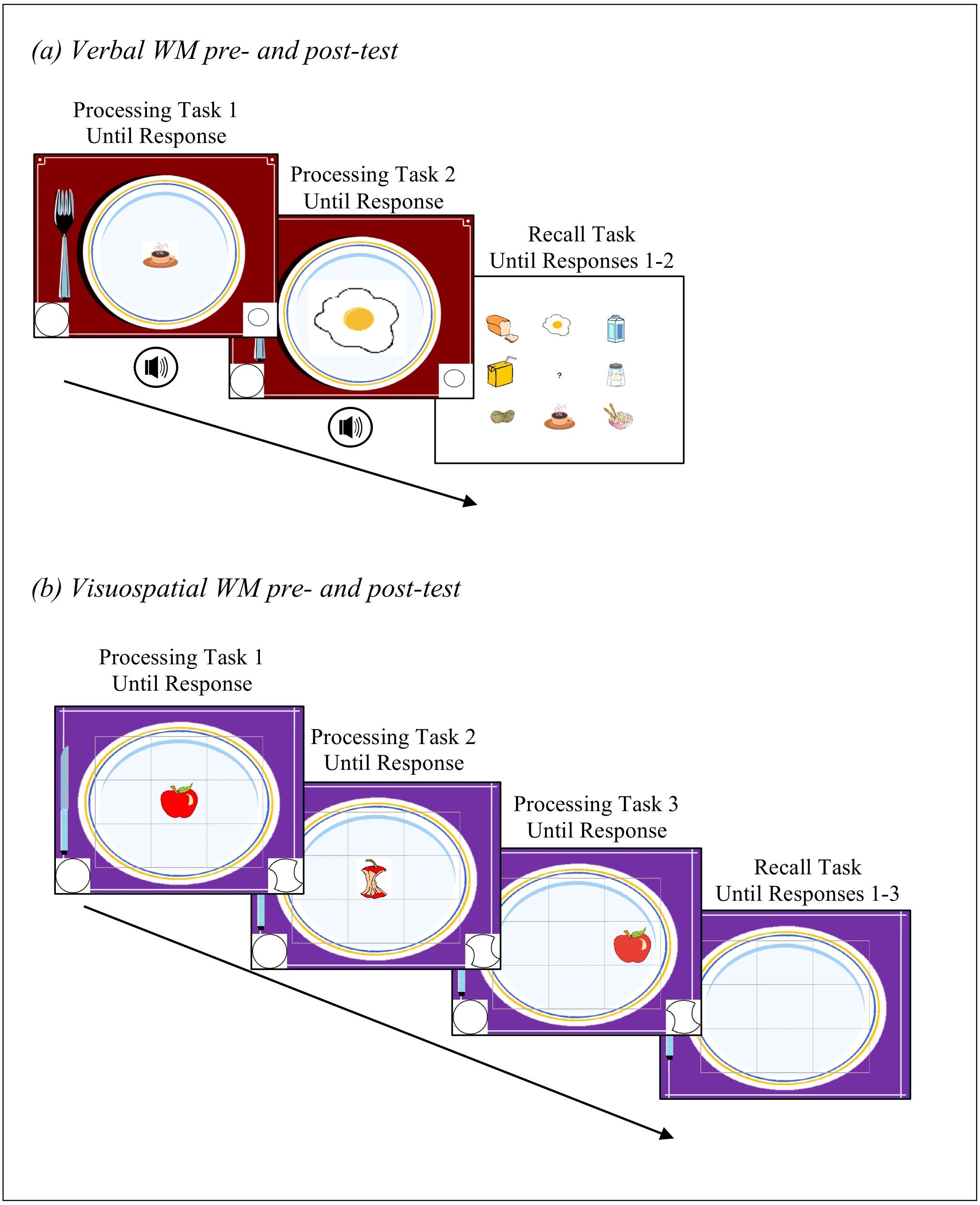

Figure 2. Example trials from (a) 2-item verbal WM pre- and post-test and (b) 3-item visuospatial WM pre- and post-test.

Working memory training. Participants either completed verbal or visuospatial WM training. Both versions contained four blocks of 12 trials. In the verbal version of the WM training, each block of trials was identical to the verbal WM pre- and post-test, apart from the stimuli, which were pictures of animals instead of food items. In the processing task of the verbal WM training, participants were asked to indicate whether the picture of the animal was in colour or black/white (Figure 3a). In the visuospatial version of the WM training, each block of trials was identical to the visuospatial pre- and post-tests, apart from the stimuli, which were pigs instead of apples. In the processing task of the visuospatial WM training, participants were asked to indicate whether the pig they saw was rotated the right way up or upside down (Figure 3b).

In the training tasks, the screen following the recall task contained either a metacognitive task (WM + metacognition groups) or a control task (WM-only groups). The metacognitive task contained two pictures, a treasure chest and rubbish bin. Participants were asked to click on the treasure chest if they thought that their responses to the previous trial had been correct and the rubbish bin if they thought their responses had been incorrect (Destan, Hembacher, Ghetti, & Roebers, 2014) (Figure 3a). The purpose of this task was to have participants reflect on their own performance in the previous trial, tapping into the monitoring aspect of their metacognitive abilities (Nelson & Narens, 1990, 1994). The control tasks contained two pictures as well, a gold arrow and a silver arrow, and participants were asked to click on one of them to continue on to the next trial (Figure 3b).

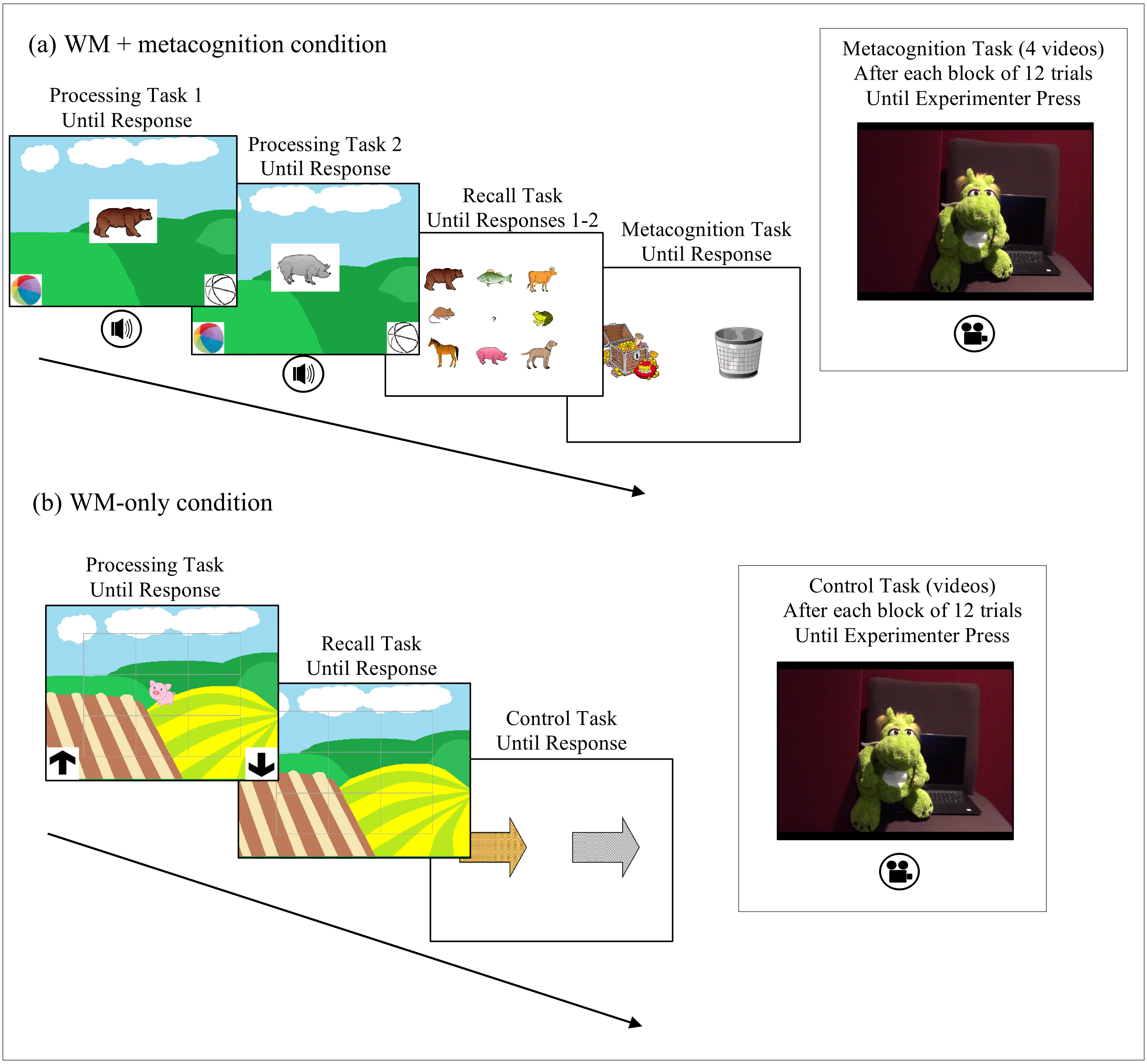

Figure 3. Example training trials from (a) 2-item verbal WM + metacognition training trial, (b) 1-item WM-only training trial.

After each block of 12 trials, a video clip of a dragon puppet appeared on the computer screen (Figure 3). The types of videos participants saw depended on their allocated condition. For the WM + metacognition groups, the puppet asked the participant questions about the WM game they were playing. In the first video, the puppet asked for an explanation on what they had to do in the game. This question was aimed towards targeting the monitoring aspect of metacognitive abilities (Nelson & Narens, 1990, 1994). The second video was similar. The puppet said they would like to play themselves and asked the participant to refresh what they had to do in each step of the game, also targeting the monitoring aspect of metacognition. In the third video, the puppet was shown playing a two-item trial of the game, correctly responding to the first item and incorrectly to the second one. When they made a mistake, they asked the participant why he/she thought they had got it wrong. The purpose of this question was to get participants to reflect on what needed to be done to carry out the task correctly, or what could result in a mistake and in turn could be corrected. This question was therefore aimed towards tapping into the control aspect of metacognition (Nelson & Narens, 1990, 1994). In the last video, the puppet asked the participant if they had any tips on how to play better. This question was aimed towards having the participants reflect on strategies they might be using and could use to improve their performance in upcoming trials, again tapping into the control aspect of metacognition. The questions for the puppet interactions in the WM + metacognition conditions were adapted from the studies of Delclos and Harrington (1991) and Moriguchi, Sakata, Ishibashi, and Ishikawa (2015).

For the WM-only groups, the puppet asked participants questions about neutral topics, such as their favourite computer game and colour, and asked for advice on drawing a picture. The questions were of a similar nature as the ones in the WM + metacognition conditions, but not the topic of the WM training game. Participants were prompted to respond to the puppet's questions in all conditions. The training was audio recorded from start to finish and participants' responses written down by an experimenter. A visual representation of the structure of the WM training is provided in Figure 4.

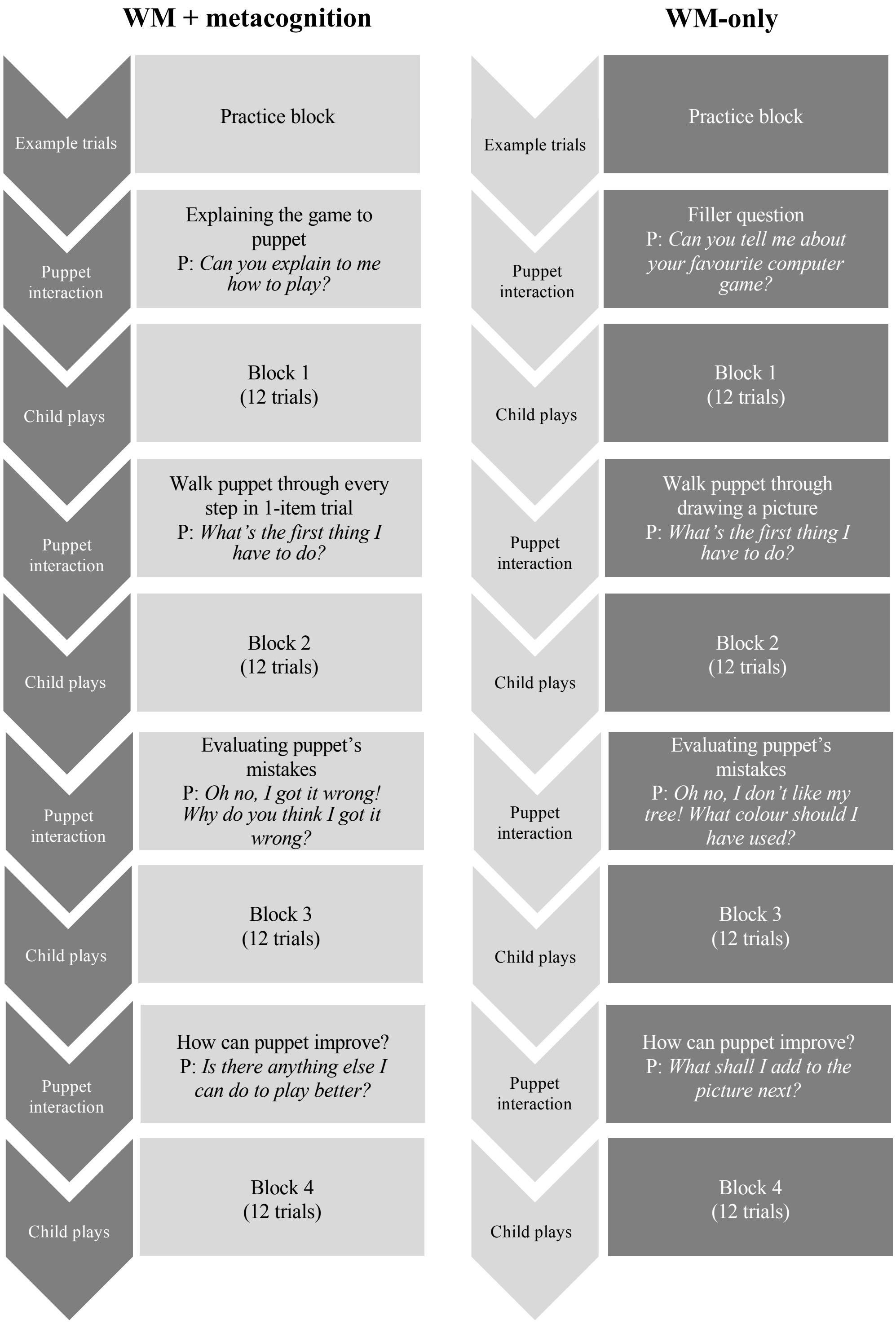

Figure 4. Visual representation of the training procedure for the WM + metacognition and WM-only conditions.

Parental questionnaire. Parents answered a short questionnaire containing items about the child and the SES of the family. The English version of the questionnaire is provided in Appendix B.

Data processing and analysis

A Dell laptop running E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) was used to present stimuli and record responses for all of the WM tasks. Responses for all WM tasks were coded in the same fashion. Points were given for each item of every trial. In order to receive a point for the items, each item had to be correctly identified, e.g. correct food or square where apple was presented, and the items had to be selected in the correct order. A total score was then computed, comprising the sum of scores for each trial. This scoring method was chosen as it minimally restricted the distribution of scores, while preventing the possibility of receiving high scores if participants responded randomly. The processing task was not included in the analyses as it was not considered to contribute to working memory performance.

T-tests were used to examine group differences at baseline and general linear models were used to assess the effects of training. Coding of responses and all statistical analyses were carried out in R (R Core Team, 2016).

Results

Baseline comparisons

The first step of the analysis was to assess whether the groups were appropriately matched at baseline. First, the WM + metacognition and WM-only groups were compared on their performance on the two matching tasks, language proficiency and verbal speed. Then, the same groups were compared on pre-test scores. These tests were conducted separately for the two age groups and types of training (verbal WM or visuospatial WM).

The results revealed significant differences in language proficiency between the WM + metacognition and WM-only groups for participants in the older age group that received visuospatial WM training, $t(34) = -3.00$, $p = .005$, with the WM + metacognition group performing better than the WM-only group. No other groups differed in performance on language proficiency or verbal speed.

Regarding pre-test performance, significant differences were found on verbal pre-test scores between the WM + metacognition and WM-only groups for participants in the younger age group that received verbal WM training, $t(43) = 2.27$, $p = .028$, with the WM-only group performing better. Significant differences were also found on verbal pre-test scores between the WM + metacognition and WM-only groups for participants in the older age group that received visuospatial WM training, $t(44) = -2.17$, $p = .036$, with the WM + metacognition group performing better. No other groups differed on pre-test scores. The two testing sites, Scotland

and Germany, were also compared on both verbal and visuospatial pre-test scores, which resulted in no significant differences.

Benefits of metacognitive elements

The first linear models assessed whether the WM + metacognition groups gained more or less from the training than the WM-only groups, testing the first hypothesis. This was carried out by examining the effects of training (WM + metacognition or WM-only) on post-test scores while taking pre-test scores and age group into account. Separate models were run for near and far transfer effects, i.e. effects of verbal WM training on verbal scores (near effects), were examined separately from effects of verbal WM training on visuospatial scores (far effects) and the same for the effects of visuospatial WM training. Results are presented in Table 2.

Table 2.
Linear models assessing the effects of (a) visuospatial WM training on visuospatial post-test scores (visuospatial near effects), (b) verbal WM training on verbal post-test scores (verbal near effects), (c) verbal WM training on visuospatial post-test scores (verbal far effects), and (d) visuospatial WM training on verbal post-test scores (visuospatial far effects), while taking into account pre-test scores and age group.

	b	*SE*	*t*	*p*
(a) Visuospatial near effects				
Visuospatial Pre-test	0.56	0.08	6.92	< .00
Age group (Older)	10.47	1.79	5.85	< .00
Training (WM + meta)	0.14	1.04	0.13	.89
(b) Verbal near effects				
Verbal Pre-test	0.57	0.11	5.23	< .00
Age group (Older)	8.54	2.13	4.01	.00
Training (WM + meta)	-1.09	1.20	-0.91	.37
(c) Verbal far effects				
Visuospatial Pre-test	0.73	0.07	10.84	< .00
Age group (Older)	4.73	1.49	3.17	.00
Training (WM + meta)	0.78	0.91	0.85	.40
(d) Visuospatial far effects				
Verbal Pre-test	0.69	0.08	8.73	< .00
Age group (Older)	6.59	1.53	4.31	< .00
Training (WM + meta)	0.20	1.01	0.20	.84

Training did not significantly predict post-test scores in any of the models, indicating that there were no differences between the WM + metacognition and WM-only groups in the effects of training. To further support these results, variance explained was assessed in a cumulative fashion for each model. First, adjusted R^2 for pre-test scores predicting post-test scores was examined, then pre-test scores and age group and finally pre-test scores, age group and training. Results from those analyses are presented in Table 3 below.

Table 3.
Cumulative Adjusted R^2 for the first four linear models.

	Cumulative variance explained (Adjusted R^2)		
	Pre-test	Pre-test + Age	Pre-test + Age + Training
Visuospatial near effects	.75	.82	.81
Verbal near effects	.68	.72	.72
Verbal far effects	.82	.84	.84
Visuospatial far effects	.74	.78	.78

Training did not increase the variance explained for any of the models, further supporting that no differences were between the WM + metacognition and WM-only training methods.

Training effects and age

The next step was to look at interactions between training and age group in order to understand whether the effectiveness of training differed between the two age groups, testing the second hypothesis. The same models were assessed, with the addition of interactions between training and age group. Results are presented in Table 4.

Table 4.
Linear models assessing the interaction between age group and training for (a) visuospatial near effects, (b) verbal near effects, (c) verbal far effects, and (d) visuospatial far effects.

	b	*SE*	*t*	*p*
(a) Visuospatial near effects				
Visuospatial Pre-test	0.55	0.08	7.01	< .00
Age group (Older)	7.88	1.98	3.98	< .00
Training (WM + meta)	-2.54	1.42	-1.79	.78
Age group * Training	5.40	2.01	2.68	.01
(b) Verbal near effects				
Verbal Pre-test	0.62	0.11	5.65	< .00
Age group (Older)	10.19	2.24	4.54	< .00
Training (WM + meta)	1.36	1.68	0.81	.42
Age group * Training	-4.96	2.43	-2.04	.04
(c) Verbal far effects				
Visuospatial Pre-test	0.73	0.07	10.76	< .00
Age group (Older)	4.45	1.73	2.57	.01
Training (WM + meta)	0.49	1.28	0.38	.70
Age group * Training	0.58	1.82	0.32	.75
(d) Visuospatial far effects				
Verbal Pre-test	0.70	0.08	8.47	< .00
Age group (Older)	6.72	1.71	3.92	< .00
Training (WM + meta)	0.38	1.43	0.27	.78
Age group * Training	-0.38	2.08	-0.18	.86

The interaction between age group and training was significant in both near effects models. This indicates that the effectiveness of training differed between the two age groups, when the pre-test and post-test measures matched the type of training (verbal WM or visuospatial WM). However, the interactions were in opposite directions in the two models. In order to further investigate these relationships, four more linear models were run examining verbal and visuospatial near effects of training, separately for the two age groups. As mentioned before, there was a significant difference in language proficiency scores at baseline between the WM + metacognition and WM-only groups for the older age group that received visuospatial training. Therefore, language proficiency was included as a predictor in the model for this group, to control for its effects. Results are presented in Tables 5-6 below.

Table 5.
Linear models assessing the visuospatial near effects by age group.

	b	*SE*	*t*	*p*
Older group				
Visuospatial Pre-test	0.50	0.12	4.35	< .00
Language proficiency	0.23	0.83	0.28	.78
Training (WM + meta)	2.74	1.86	1.47	.15
Younger group				
Visuospatial Pre-test	0.67	0.12	5.47	< .00
Training (WM + meta)	-2.65	1.10	-2.41	.02

Table 6.
Linear models assessing the verbal near effects by age group.

	b	*SE*	*t*	*p*
Older group				
Verbal Pre-test	0.61	0.16	3.79	< .00
Training (WM + meta)	-3.55	2.00	-1.78	.08
Younger group				
Verbal Pre-test	0.67	0.16	4.29	< .00
Training (WM + meta)	1.48	1.44	1.03	.31

Training significantly predicted post-test scores for the younger group that received visuospatial training. However, the results suggest that the WM-only training group gained more from the training than the WM + metacognition group, opposite to the hypothesised direction. These results somewhat clarify the opposite interactions between age group and training in the verbal and visuospatial near effects models presented in Table 4. As is shown in Tables 5-6, the directions of the effects of training on post-test scores are opposite for the age groups between the verbal and visuospatial near effects models. However, the effects in only one of the models were significant, so these results cannot be interpreted with any confidence.

To further illustrate these relationships, plots showing the effects of training by age group are provided in Figure 5.

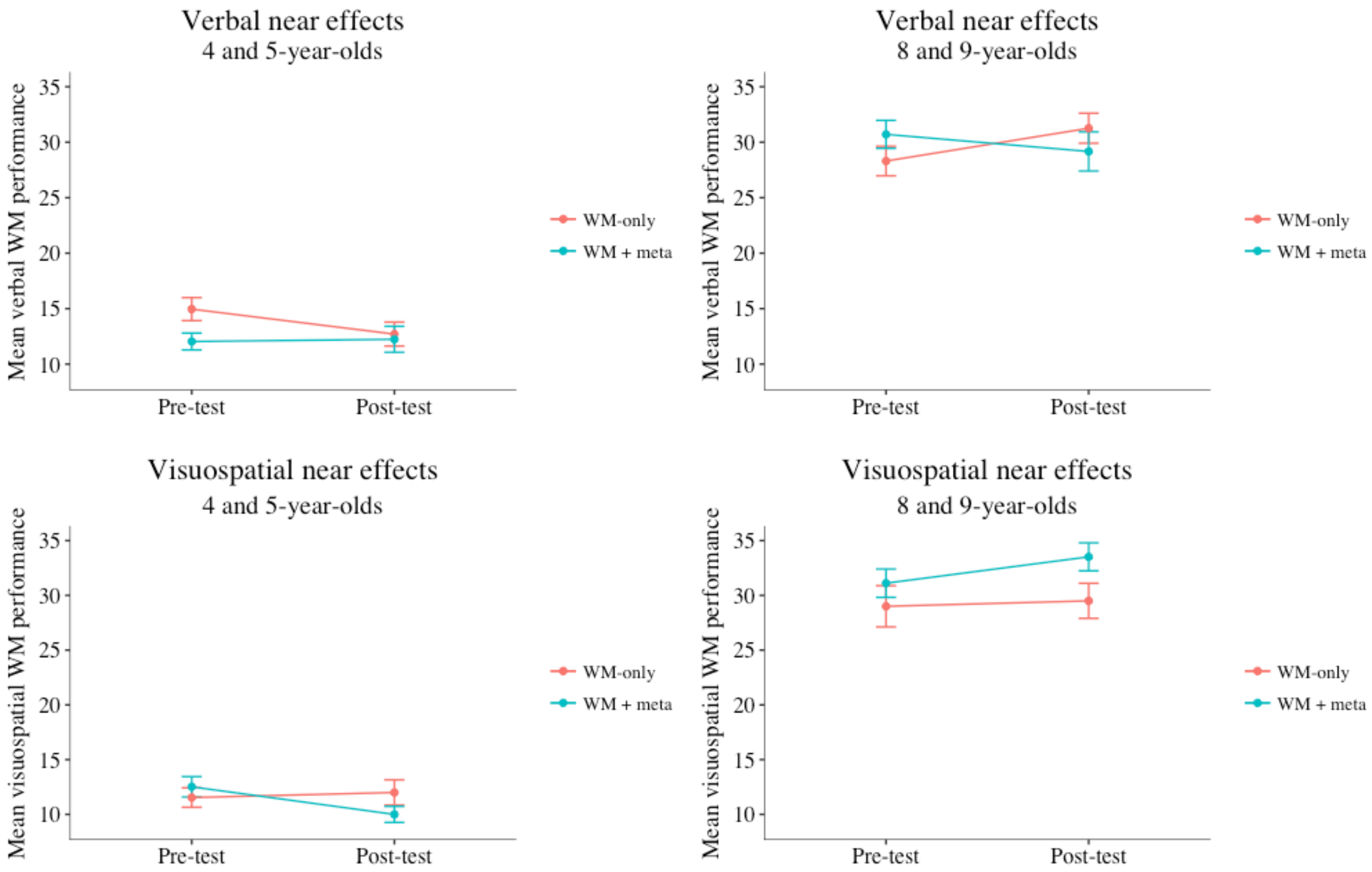

Figure 5. Effectiveness of near training effects for verbal and visuospatial training split by age group. Error bars denote standard errors from the mean.

Figure 5 further shows that the training did not have the hypothesised effect on performance. There was either no difference between the WM + metacognition and WM-only groups, or the difference was opposite to the hypothesised direction, with the WM + metacognition group gaining less from training than the WM-only group (Visuospatial near effects, 4 and 5-year-olds).

Training effects and SES

In order to test the third hypothesis, that the effects of training would differ by family SES, a final set of liner models was run including interactions between SES and training. The Family Affluence Scale (Currie et al., 2008) (questions 17-20 in Appendix B) was used as an indicator of SES. Results are presented in Tables 7-8.

Table 7.
Descriptive statistics for scores on the Family Affluence Scale by site.

	N	*M*	*SD*	*Min*	*Max*
Scottish sample	101	5.95	1.71	1.00	9.00
German sample	79	6.06	1.81	1.00	9.00

Table 8.
Linear models assessing the interactions between family SES and training for (a) visuospatial near effects, (b) verbal near effects, (c) verbal far effects, and (d) visuospatial far effects.

	b	*SE*	*t*	*p*
(a) Visuospatial near effects				
Visuospatial Pre-test	0.58	0.08	6.86	< .00
Age group (Older)	9.47	1.90	5.04	< .00
Family affluence	0.33	0.44	0.75	.46
Training (WM + meta)	0.19	4.45	0.04	.97
Family affluence * Training	-0.02	0.68	-0.03	.98
(b) Verbal near effects				
Verbal Pre-test	0.60	0.11	5.20	< .00
Age group (Older)	8.23	2.26	3.64	< .00
Family affluence	0.44	0.54	0.82	.41
Training (WM + meta)	0.87	4.39	0.20	.84
Family affluence * Training	-0.37	0.74	-0.50	.62
(c) Verbal far effects				
Visuospatial Pre-test	0.75	0.08	9.56	< .00
Age group (Older)	4.78	1.69	2.82	.01
Family affluence	-0.01	0.43	-0.01	.99
Training (WM + meta)	0.60	3.39	0.18	.86
Family affluence * Training	0.04	0.57	0.08	.94
(d) Visuospatial far effects				
Verbal Pre-test	0.68	0.08	8.16	< .00
Age group (Older)	7.11	1.58	4.50	< .00
Family affluence	-0.12	0.43	-0.29	.78
Training (WM + meta)	-5.19	4.23	-1.23	.22
Family affluence * Training	0.83	0.64	1.29	.20

Interactions between family affluence and training were not significant in any of the models, indicating that the effectiveness of training did not differ by family SES.

Discussion

The current study assessed whether metacognitive elements would improve WM training in a single training session. Statistical analyses showed that this was not the case for neither near effects nor far effects. No significant differences were found between the post-test performance of the WM + metacognition and WM-only groups, with one exception where the analyses were broken up by age group. Significant differences between WM + metacognition and WM-only groups were found, but in the opposite direction of the hypothesis, with the WM-only group gaining more from training than the WM + metacognition group. The first hypothesis was thus not supported. This indicates that participants did not benefit from the metacognitive elements of the training, i.e. reflecting on their own abilities in the WM training tasks did not result in improved performance on the post-tests, compared to those who received WM training that did not include metacognitive elements.

The second hypothesis stated that the effects of training would differ between the two age groups in the study. This was partly supported. Interactions between age group and training were significant, but only for the near effects models, i.e. effects of verbal WM training on verbal WM post-scores and visuospatial WM training on visuospatial WM post-scores. A closer examination of these relationships revealed a paradoxical result. For visuospatial near effects in the older group, the WM + metacognition group seemed to gain more from training than the WM-only group. This was opposite in the younger group, with the WM-only group gaining more from training than the WM + metacognition group. For the verbal near effects, however, the WM + metacognition group seemed to be gaining less from training than the WM-only group, in the older age group, but more in the younger age group. The effects of training were though only significant in one of these four models, so these results cannot be interpreted with any confidence.

The third hypothesis, that the effects of training would differ by SES, was not supported. Interactions between SES and training were not significant, neither for near effects nor far effects.

Regarding baseline comparisons, there were significant differences in language proficiency or pre-test scores between the WM + metacognition and WM-only groups on three occasions. It would have been preferable for the groups to be more equally matched, however, pre-test scores were included as a predictor in all models, so those differences should not have had an effect on the results. Similarly, where there was a difference in language proficiency, those scores were included as a predictor in order to take them into account. No baseline differences were found between the two testing sites, Scotland and Germany.

Some site differences were apparent, however, in the measures included in the parental questionnaire, which resulted in some constraints regarding the analysis of these variables. First, the distribution in parent's and partner's education differed considerably between the two testing sites. As a consequence, this variable was not used as an indicator of SES in the analyses, which would have been preferable. Second, some methodological difficulties were experienced when working with the income data. Through collaboration with colleagues in Germany, it was decided to give participants the option to report their income before or after tax and per month or per year, in order to accommodate cultural differences in how income is discussed in the two countries. This led to challenges in analysing the data, as different tax levels for each country needed to be taken into account. As time did not allow for standardisation of this variable, income was not included in the analysis as an indicator of SES. For these reasons, and in order to prevent the models from becoming too complex with multiple indicators of SES included, it was decided to only include the Family Affluence Scale in the current analyses. It would though be interesting to incorporate alternative indicators of SES, such as number of after-school activities, as well as the above mentioned education and income in further analyses.

There are several possible explanations as to why the hypotheses were not supported in the current study. First and foremost, matching tasks, pre-tests, training and post-tests were all carried out in a single session. As Diamond and Ling (2016) mention, for studies that showed an effect of executive function training, more training gains were observed as the number of training sessions increased. As the current study only included one session, it was not expected that training would have large effects, and as a consequence, the training itself might have been too limited for the metacognitive elements of the WM training to come into effect. Therefore, participants quite possibly did not get a proper chance to increase their engagement in proactive control. If more sessions had been included in this study, as is the aim for the larger project for which this study serves as a pilot, participants might have had more opportunities to reflect on their performance and alter their control strategies, which could therefore have resulted in increased training gains for the WM + metacognition group.

Another possible explanation also relates to the limitation of only having a single session. As all the measures had to be fitted into one session, it ended up lasting for a substantial amount of time. Considerable fatigue was observed towards the end of the session for many participants, especially in the younger group. The post-test measures were, for obvious reasons, at the end of the session, so even if the training was having an effect, the benefits of training might have been negatively impacted by the fatigue of participants.

The literature suggests that those with lower executive function skills improve more from training (Diamond & Ling, 2016). It was therefore hypothesised that the younger group would gain more from the training than the older group. The current results did not reflect this. Possible explanations for this discrepancy with previous studies are, as mentioned previously, fatigue of the younger participants and the single session possibly not providing enough opportunity for the metacognitive elements to have an effect at all.

Another question to consider is if the tasks themselves encouraged the younger children enough to use proactive control. Chevalier et al. (2015) showed how young children overcame their bias towards reactive control and engaged in proactive control when the experimental situation was manipulated so reactive control was made more difficult. In the current study, the WM tasks did increase in difficulty dependent on the participants' performance, but there was no manipulation of task cues, as in the study of Chevalier et al. (2015). The question therefore arises whether the task opened up enough opportunities for the younger participants to adjust their control strategies and therefore improve their WM performance.

The current findings also contradicted results from previous studies (Blair & Raver, 2014) with regards to the effects of training differing by SES. The aforementioned explanations relating to the limitations of a single session, may explain these results as well. However, there is also reason to believe that the current sample was not quite representative of the population with regards to SES. For example, the participant database at the University of Edinburgh, from which over half of the Scottish sample was recruited, is known to consist of families of relatively high SES. Limited variation in SES in the current sample could therefore, at least in part, explain the observed discrepancy between the current findings and existing literature.

Much has been learned in the process of this pilot, which will be valuable for designing a high quality intervention, as is the next aim of the research group. In addition to the previously discussed limitations, such as the use of a single session, length of the session and representability of the sample, some practical obstacles also occurred. One of these was relying on the use of a computer mouse in the WM tasks. It seemed that many of the participants, mostly in the younger group, had very little prior experience with traditional computers, as touch screen computers have become increasingly popular. As a consequence, some of them had trouble controlling the mouse, which in some cases resulted in the experimenter taking over the use of the mouse while the participants used their fingers to point to the items they deemed correct. As a result, response times had to be completely disregarded from all analyses. It is recommended that future studies using computerised tasks, which require young participants to respond on screen, shift from the use of regular laptops or computers to the use of touch screen devices, as they seem to be much more familiar to young children.

The next steps of the research group will be to take the intervention piloted in the current study further. The training paradigm will be delivered in multiple sessions per participant. Each session will ideally be shorter than the one in the current study, attempting to limit the fatigue of participants. Furthermore, the project will be carried out in primary schools, with the aim of targeting children from low SES families. The knowledge gained by this pilot will be incorporated in the larger project, with the goal of creating a high quality intervention.

Conclusion

WM training including metacognitive elements did not improve WM scores at post-test more than WM training without metacognitive elements. The results furthermore showed that younger children did not gain more from the WM + metacognition training than the older group and that effectiveness of training did not differ by SES. There are several possible explanations for these results. First, all data were collected in a single session, limiting the opportunity for metacognitive reflection and therefore adjustments in cognitive control, which was the purpose of the WM + metacognition training. In addition, as all measures were fitted into one session, it took quite a long time, which resulted in fatigue towards the end of the session for many participants. Second, the sample was not representative of the population with regards to SES, which might also explain the lack of interaction between WM training and SES.

The next steps following on from this study will be to test the current intervention in multiple training sessions. This will be carried out in primary schools with the aim of targeting children from low SES backgrounds.

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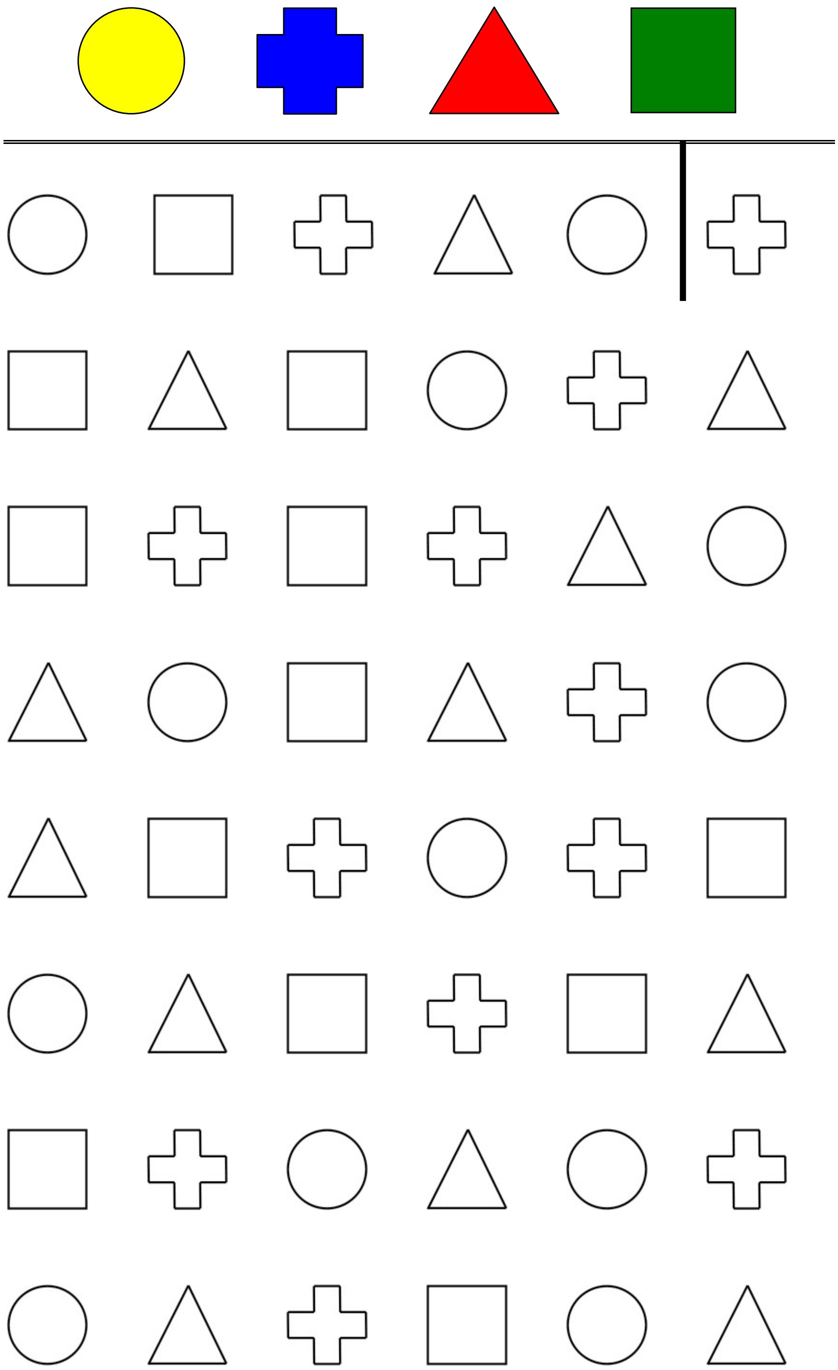
Appendix A

Colour-naming task



Score (45 sec): ________

Appendix B

Parental questionnaire

Edinburgh Child Development Study

ALL INFORMATION REMAINS STRICTLY CONFIDENTIAL

IF IN DOUBT, PLEASE FEEL FREE TO SKIP ANY QUESTIONS

Study ID:____________________ Today's Date: _________________________

Child's Sex: ☐ Male ☐ Female

Child's Date of birth (DD/MM/YY):____/____/____

Child's Age:______years ________months

Your relationship to child (e.g., mother, father, caregiver):____________________

1. Does your child have any siblings?

   ☐ No ☐ Yes (birth order (e.g. 1st of 2):___________________________

2. Does your child have any imaginary friends?

   ☐ No ☐ Yes (if yes, how many?):____________________________________

3. What language(s) do you speak at home?

   Please specify:______________________________________

4. Does your child attend any after-school activities?

   ☐ No ☐ Yes (please specify):_______________________________________

5. Is your child undergoing any pharmacological treatment?

   ☐ No ☐ Yes (please specify:_______________________________________)

6. How much did your baby weigh at birth? ___________ lbs/oz OR grams (please circle)
7. What is your occupation? ____
8. What is your partner's occupation? ____

9. What is your highest academic qualification?

GCSE (or equivalent)	☐
A-Levels (or equivalent)	☐
Vocational Training	☐
Bachelor’s Degree	☐
Master’s Degree	☐
Doctorate	☐
None of the Above (please specify)	☐

10. What is your partner’s highest academic qualification?

GCSE (or equivalent)	☐
A-Levels (or equivalent)	☐
Vocational Training	☐
Bachelor’s Degree	☐
Master’s Degree	☐
Doctorate	☐
None of the Above (please specify)	☐

11. What is your current postcode?

____

12. How many people are currently living in your household, including yourself?

____

13. Of the people living in your household, how many are children under the age of 18?

____

14. Of the adults living in your household, how many currently bring income into the household?

____

15. Please could you estimate your total combined family income for the household, either by month or by year. Please also indicate if this is before or after tax. This should include income from all sources, such as wages, rent from properties, benefits, help from relatives and so on.

Per Month ___________ OR Per Year ____________

Before/After Tax? (Please Circle) Before/After Tax? (Please Circle)

17. Does your family own a car, van or truck?

No ☐

Yes, one ☐

Yes, two or more ☐

18. Does your child have his or her own bedroom?

Yes ☐

No ☐

19. During the last 12 months, how many times did you travel away on holiday with your family?

Not at all ☐

Once ☐

Twice ☐

More than twice ☐

20. How many computers does your family own?

None ☐

One ☐

Two ☐

More than two ☐

21. Has your child ever been referred (e.g. by your GP) AND/OR diagnosed with any of the following? (Please tick all that apply)

- Language Delay/Disorder ☐
- Developmental Delay ☐
- Hyperactivity/Attention Deficit Disorder (ADHD, ADD) ☐
- Dyspraxia (Coordination and movement disorder) ☐
- Dyslexia (Reading disorder) ☐
- Hearing or visual difficulties ☐
- Autistic Spectrum Disorder (including Asperger's Syndrome) ☐
- Physical Disability ☐
- Genetic/chromosomal abnormality ☐
- Epilepsy (seizure disorder) ☐
- Tourette's Syndrome (Tic disorder) ☐
- Tuberous Sclerosis ☐

Any other medical condition: ______________________